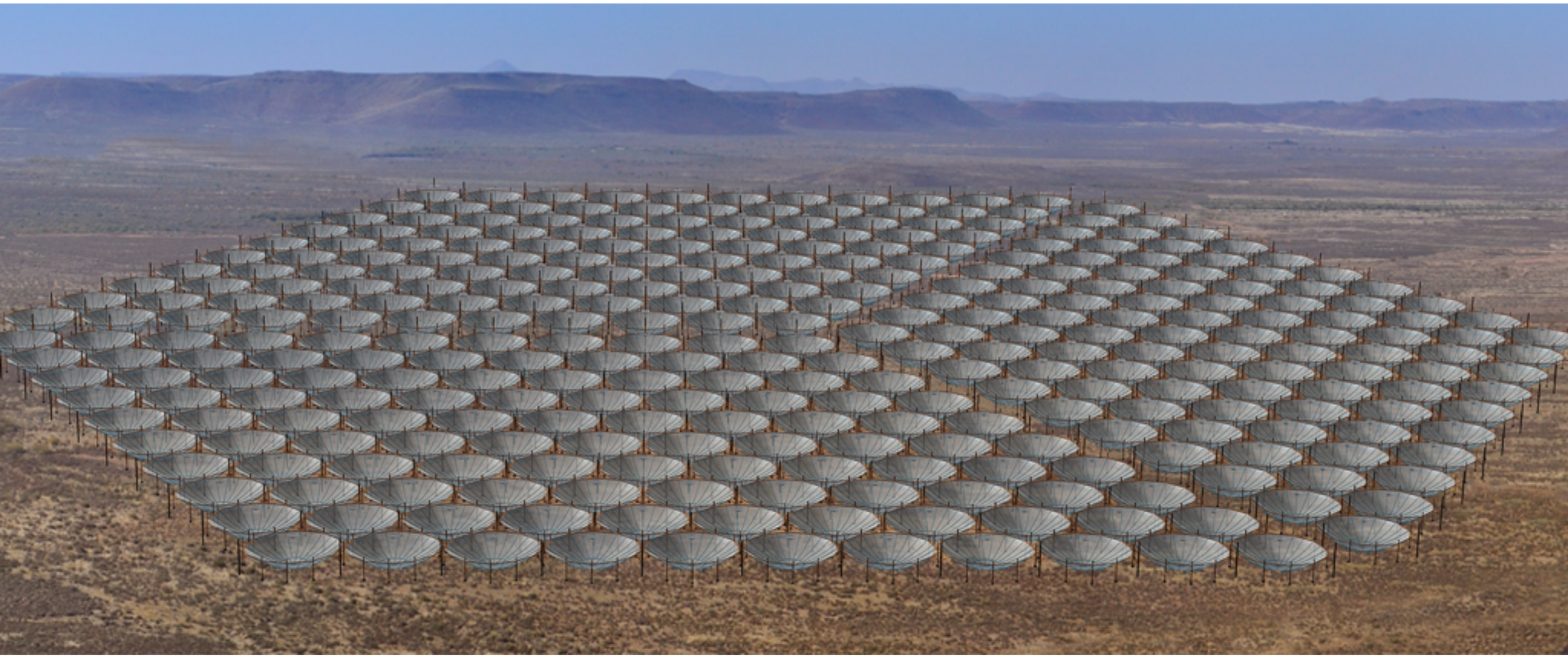
Hydrogen Epoch of Reionization Array

Adrian Liu, Hubble Fellow, UC Berkeley

What is HERA?

A **funded (!)** interferometer array of 350 dishes of 14 m diameter to do low-frequency 21 cm cosmology



154 m

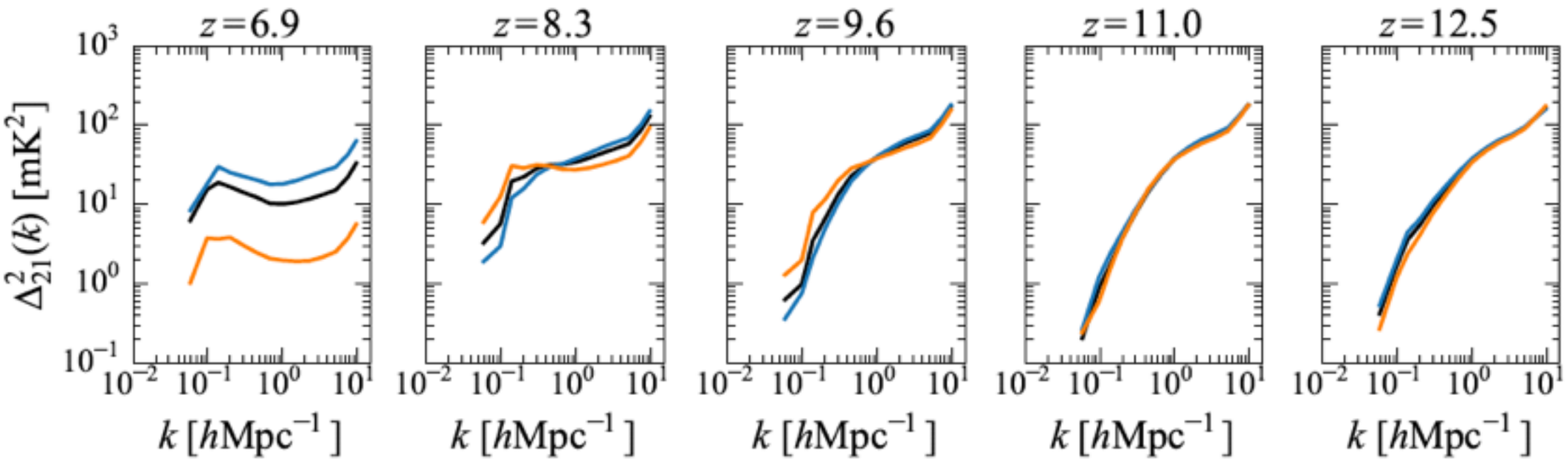
What is HERA?

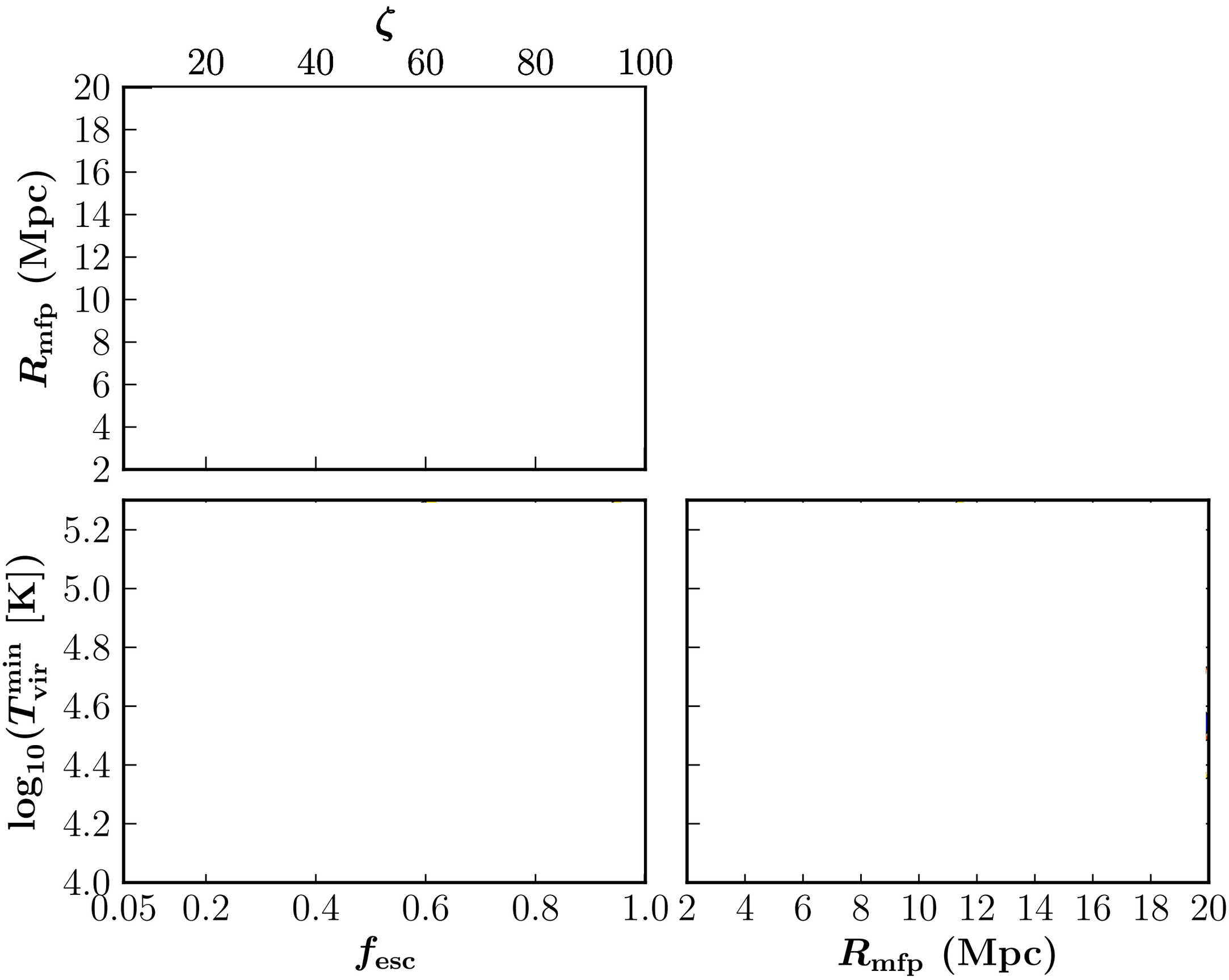
- 350 dishes, 14m diameter each.
- Primary science focus: $6 < z < 13$, with possibility of $5.5 < z < 27$.
- Drift-scan instrument.
- High significance measurement of 21cm power spectrum: $\sim 20\sigma$ to $\sim 90\sigma$ depending on foregrounds

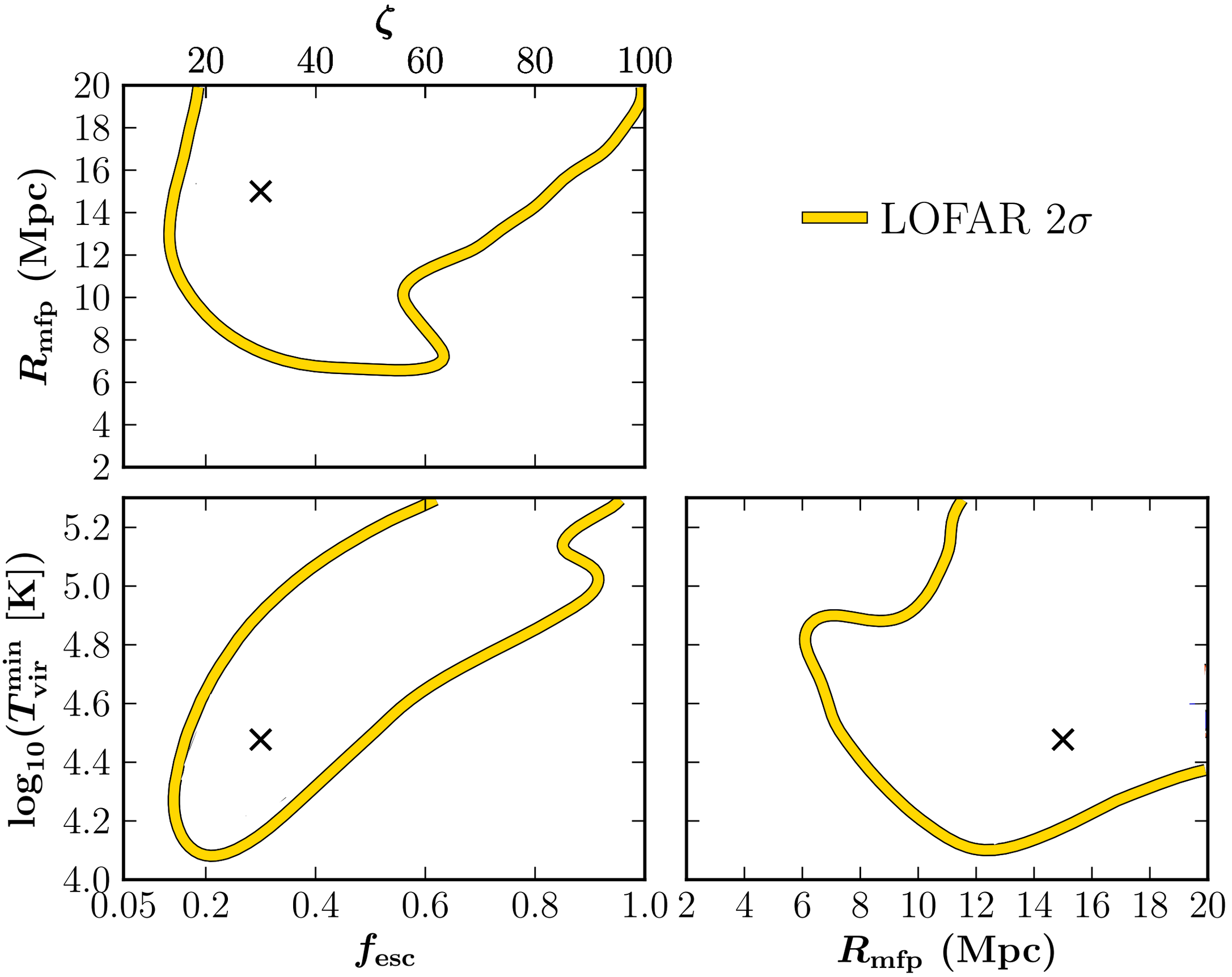
HERA is primarily designed to access the Epoch of Reionization…

A three-parameter reionization model

- ζ: ionizing efficiency of first galaxies
- T_{vir}: minimum virial temperature (proxy for mass) of first ionizing galaxies
- R_{mfp}: mean free path of ionizing photons


$z=6.9$
$z=8.3$
$z=9.6$
$z=11.0$
$z=12.5$
$\Delta^2_{21}(k)$ [mK^2]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2} 10^{-1} 10^0 10^1
k [hMpc^{-1}]


ζ
20
40
60
80
100
$R_{\rm mfp}$ (Mpc)
20
18
16
14
12
10
8
6
4
2
$\log_{10}(T_{\rm vir}^{\rm min}$ [K])
5.2
5.0
4.8
4.6
4.4
4.2
4.0
0.05
0.2
0.4
0.6
0.8
1.0
$f_{\rm esc}$
2
4
6
8
10
12
14
16
18
20
$R_{\rm mfp}$ (Mpc)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LOFAR 2σ
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4.0
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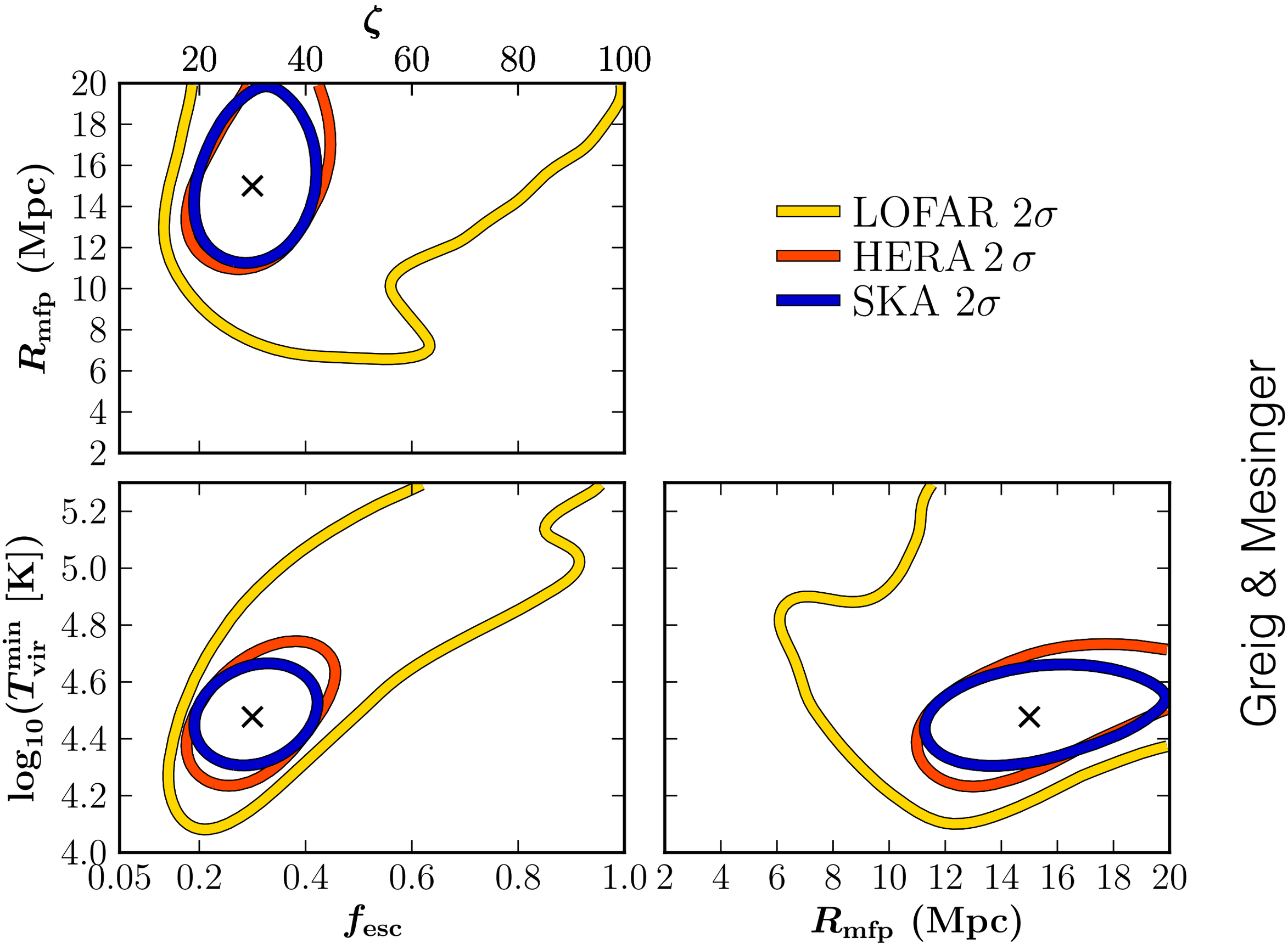
$R_{\rm mfp}$ (Mpc)


ζ
20
40
60
80
100
$R_{\rm mfp}$ (Mpc)
2
4
6
8
10
12
14
16
18
20
LOFAR 2σ
HERA 2 σ
SKA 2σ
$\log_{10}(T_{\rm vir}^{\rm min}$ [K])
4.0
4.2
4.4
4.6
4.8
5.0
5.2
0.05
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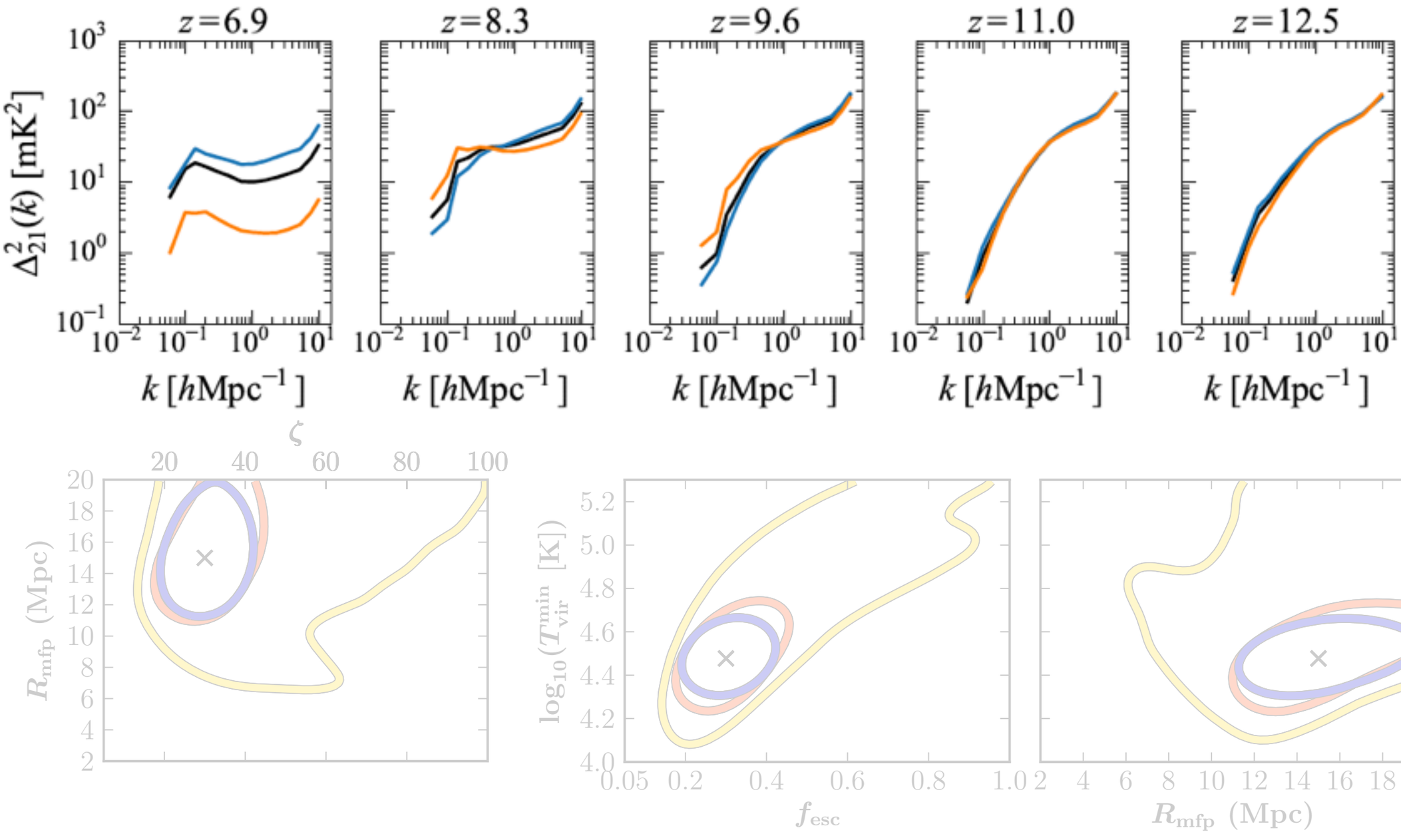
0.4
0.6
0.8
1.0
$f_{\rm esc}$
$R_{\rm mfp}$ (Mpc)
Greig & Mesinger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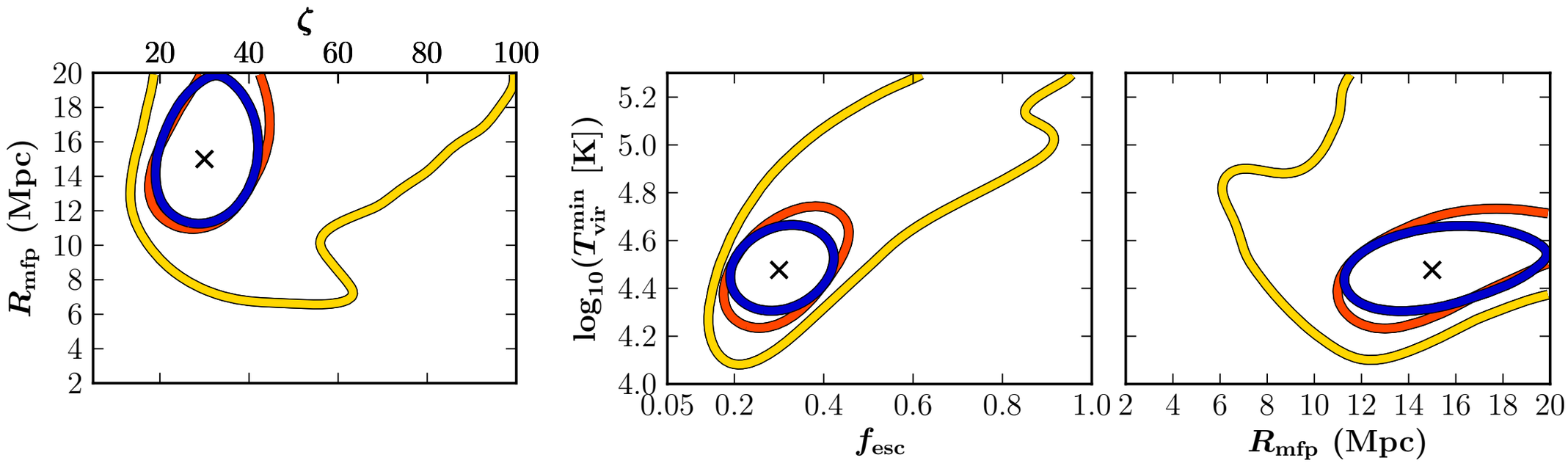
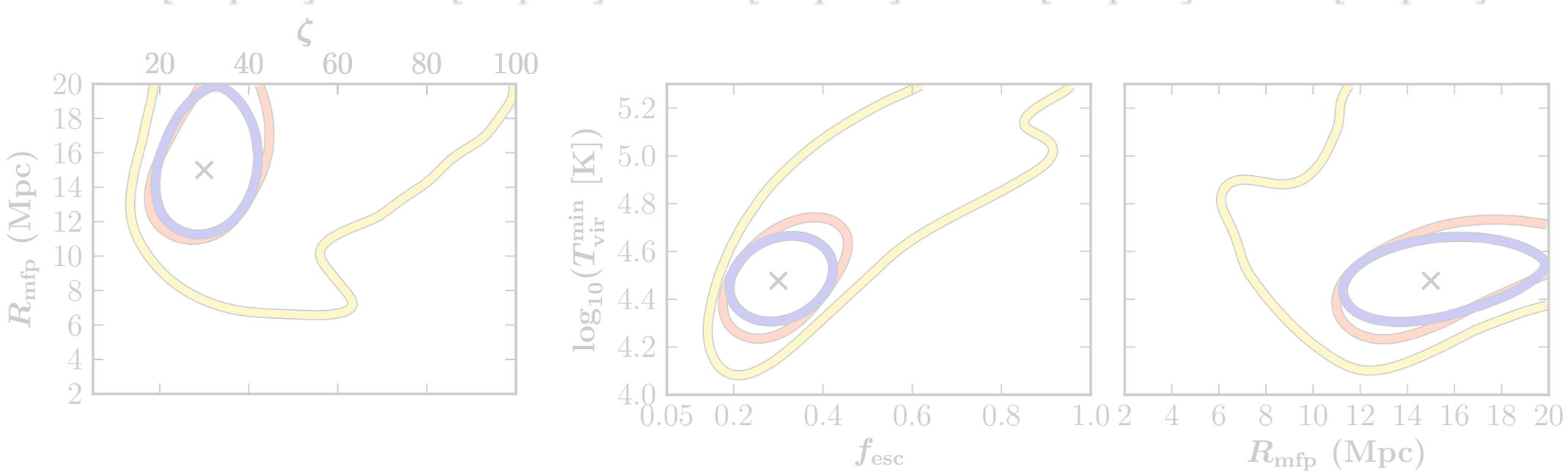

ζ
$R_{\rm mfp}$ (Mpc)
$\log_{10}(T_{\rm vir}^{\rm min})$ [K])
$f_{\rm esc}$
$R_{\rm mfp}$ (Mpc)

$x_{\rm HII}$
Density−weighted ion. frac. $\overline{x_{\rm HII}(1+\delta_b)}$
Ionized fraction $\overline{x}_{\rm HII}$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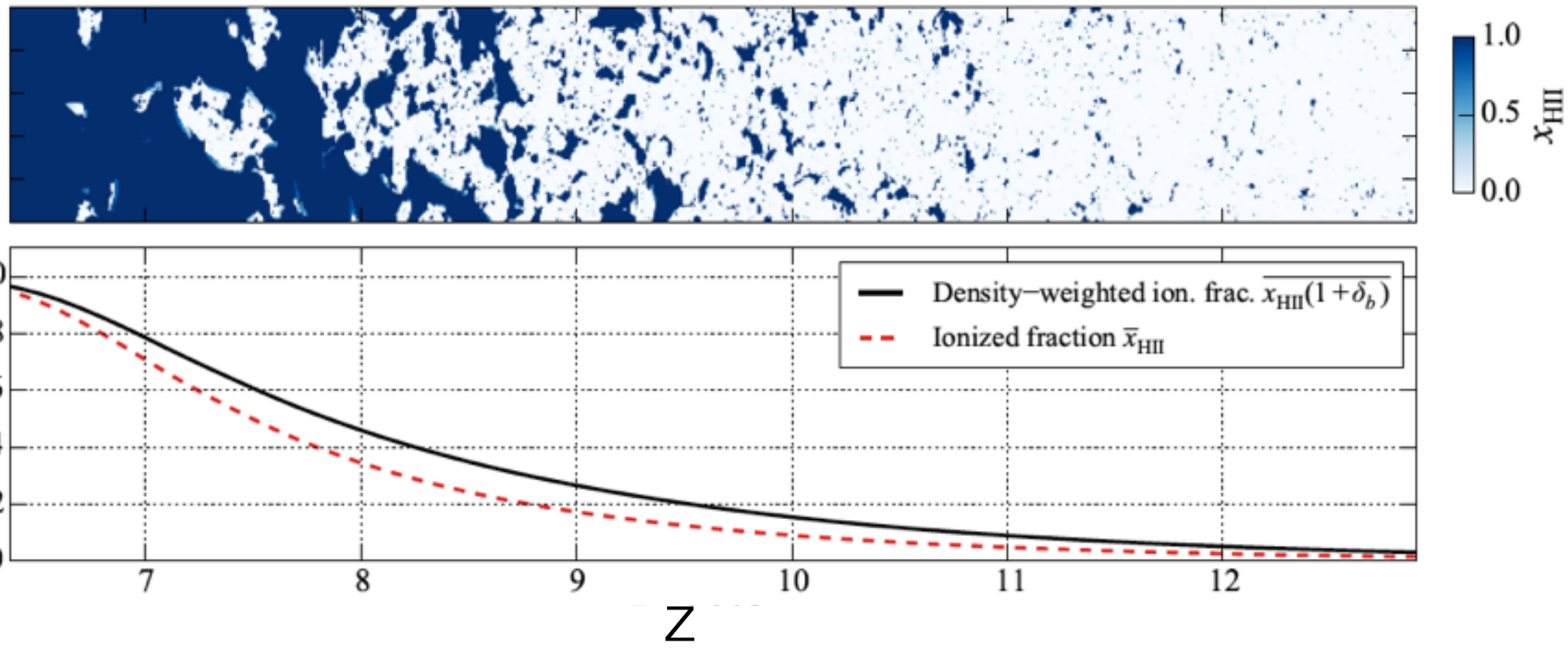
1.0
0.5
0.0
$x_{\rm HII}$
1.0
0.8
0.6
0.4
0.2
0.0
7
8
9
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11
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Density−weighted ion. frac. $\overline{x_{\rm HII}(1+\delta_b)}$
Ionized fraction $\overline{x}_{\rm HII}$
Z

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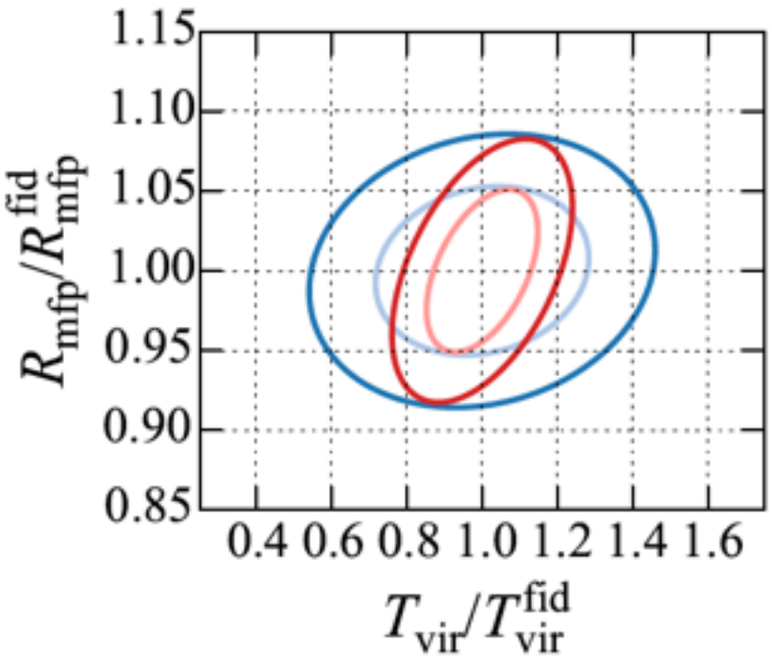
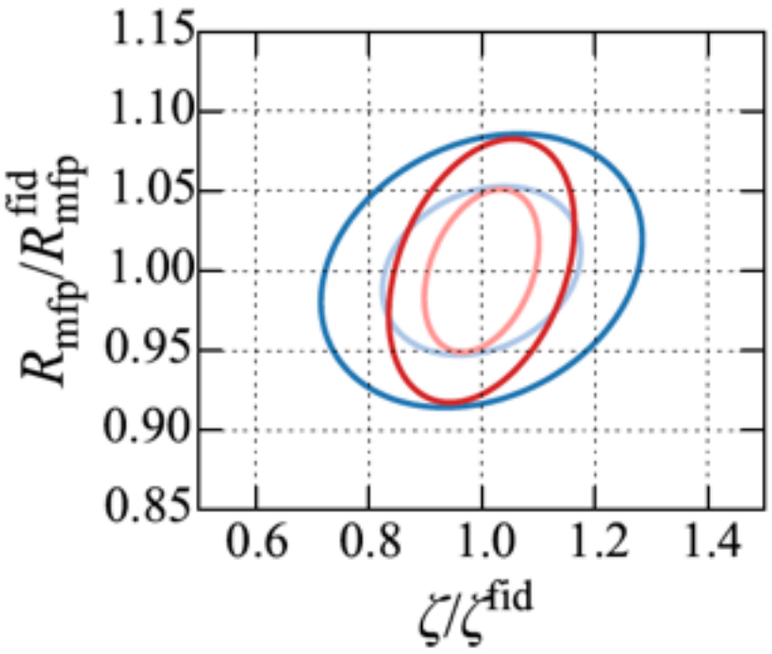
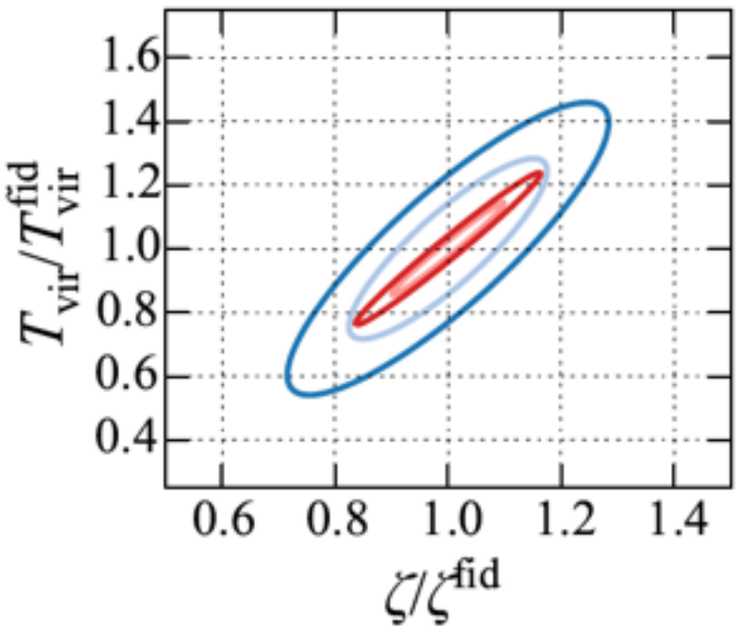
Cosmological parameter uncertainties are non-negligible for HERA



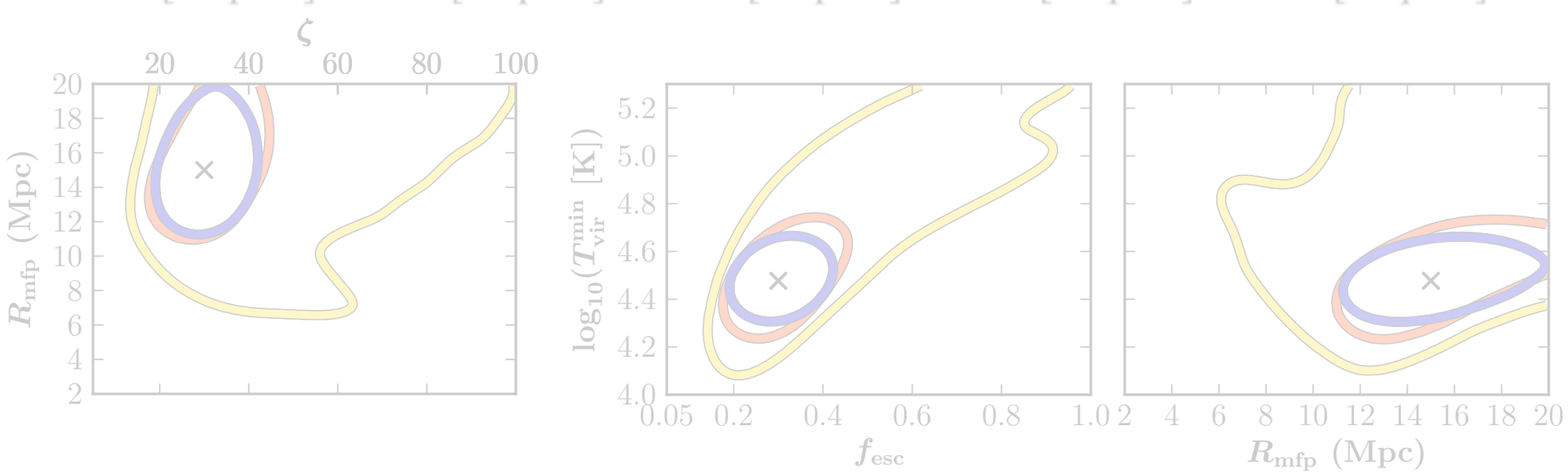


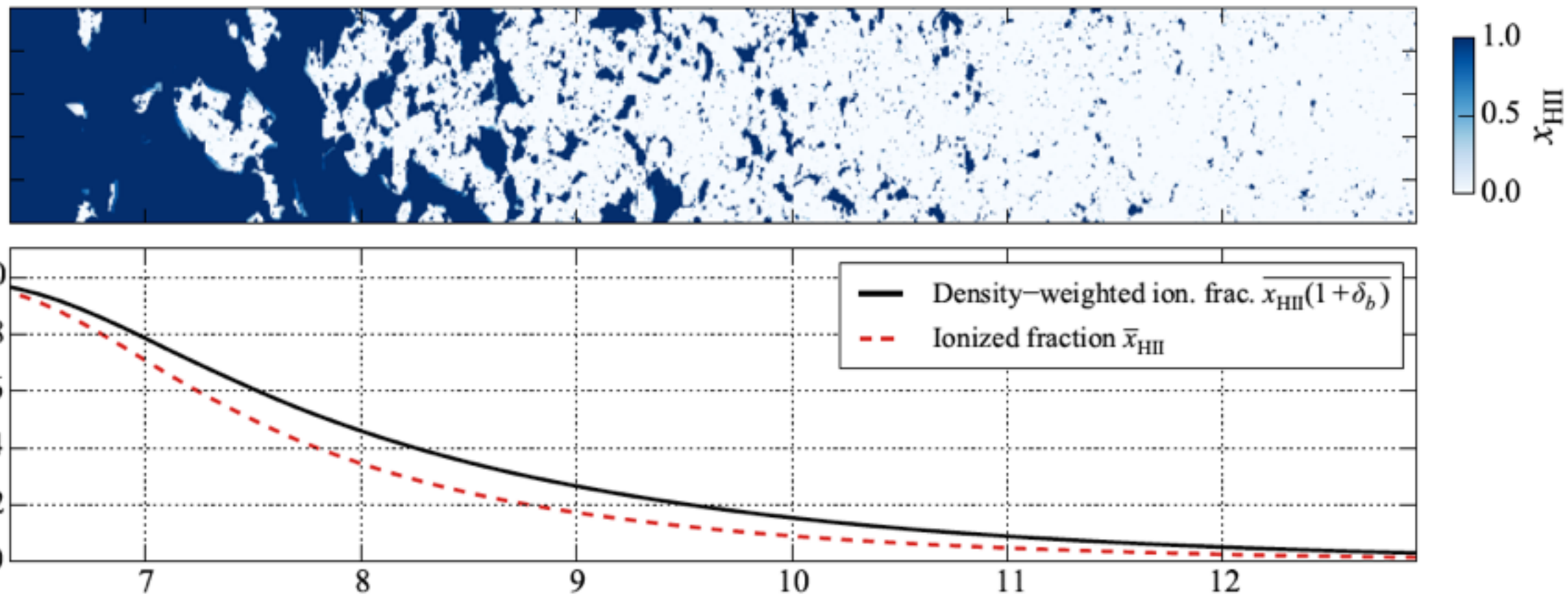


Cosmo params fixed

Cosmo params varied

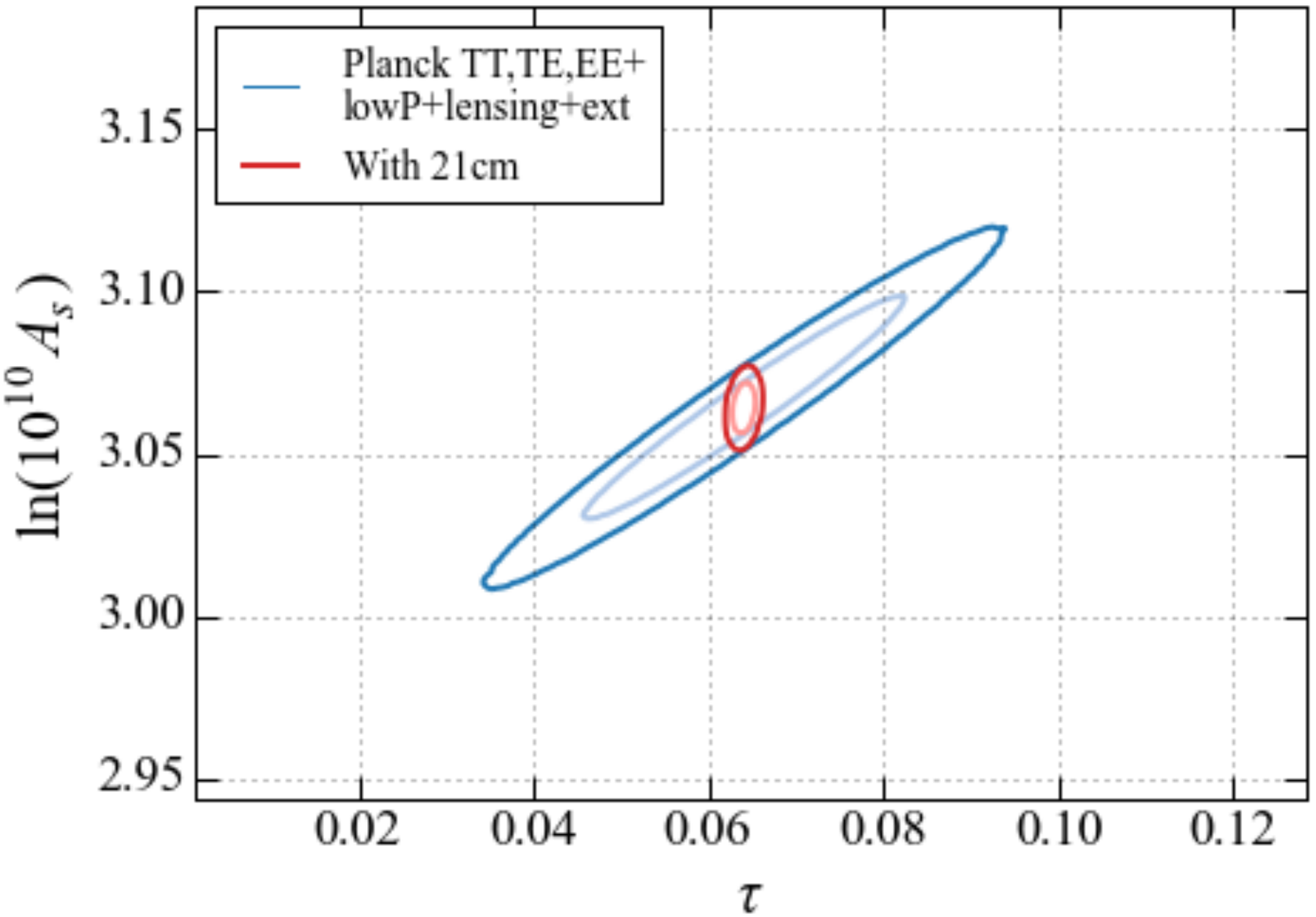
AL & Parsons (2016)





$$\tau \propto \int \langle (1 - x_{HI})\delta_b \rangle dz$$

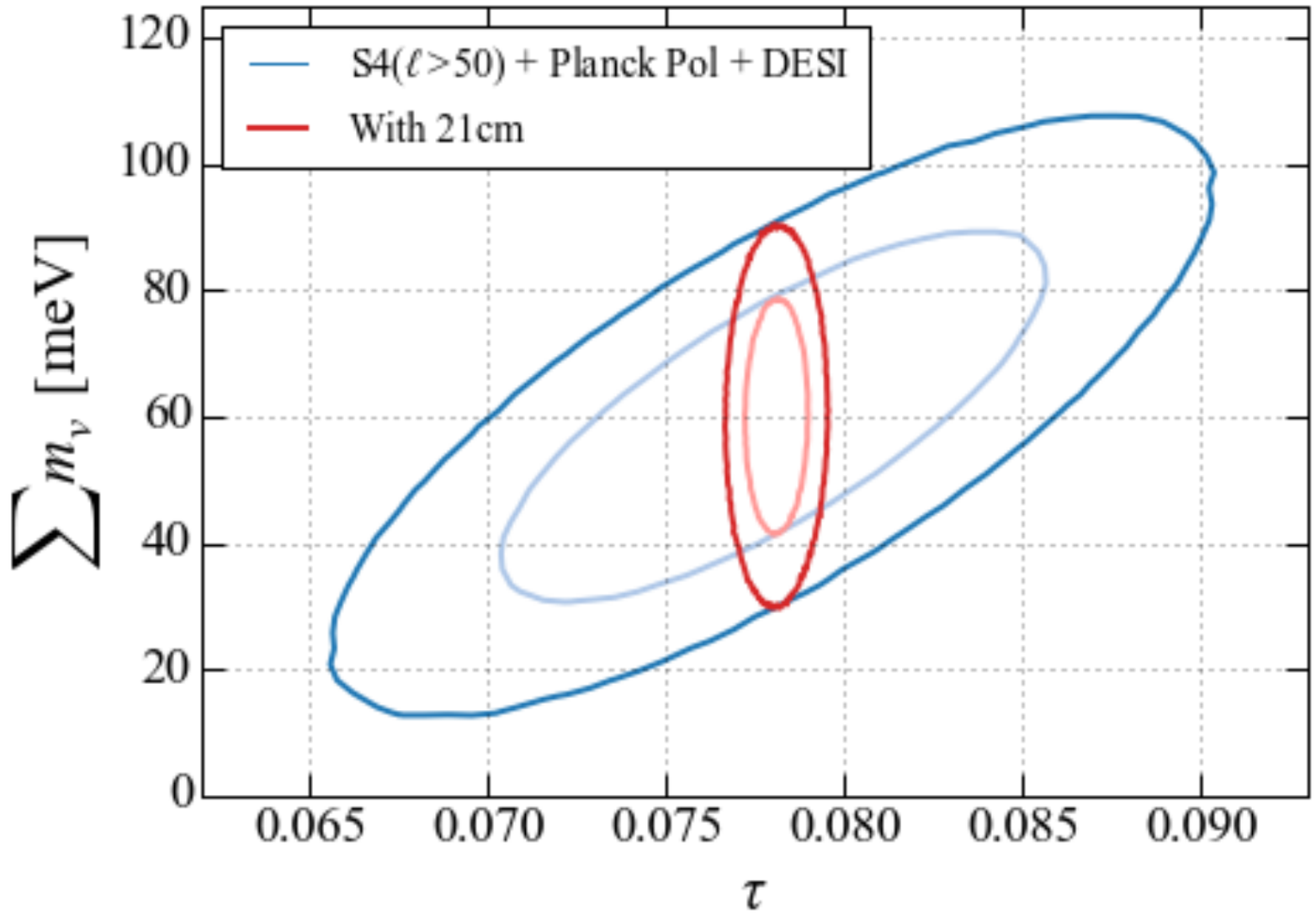
21cm information breaks the degeneracy between the amplitude of fluctuations and the optical depth



AL et al. (2016)

$$\Delta \ln(10^{10} A_s) = \pm 0.023 \longrightarrow \pm 0.0053$$

Both A_s and the neutrino mass can affect small scale power, leading to degeneracies



Allison et al. (2015)

AL et al. (2016)

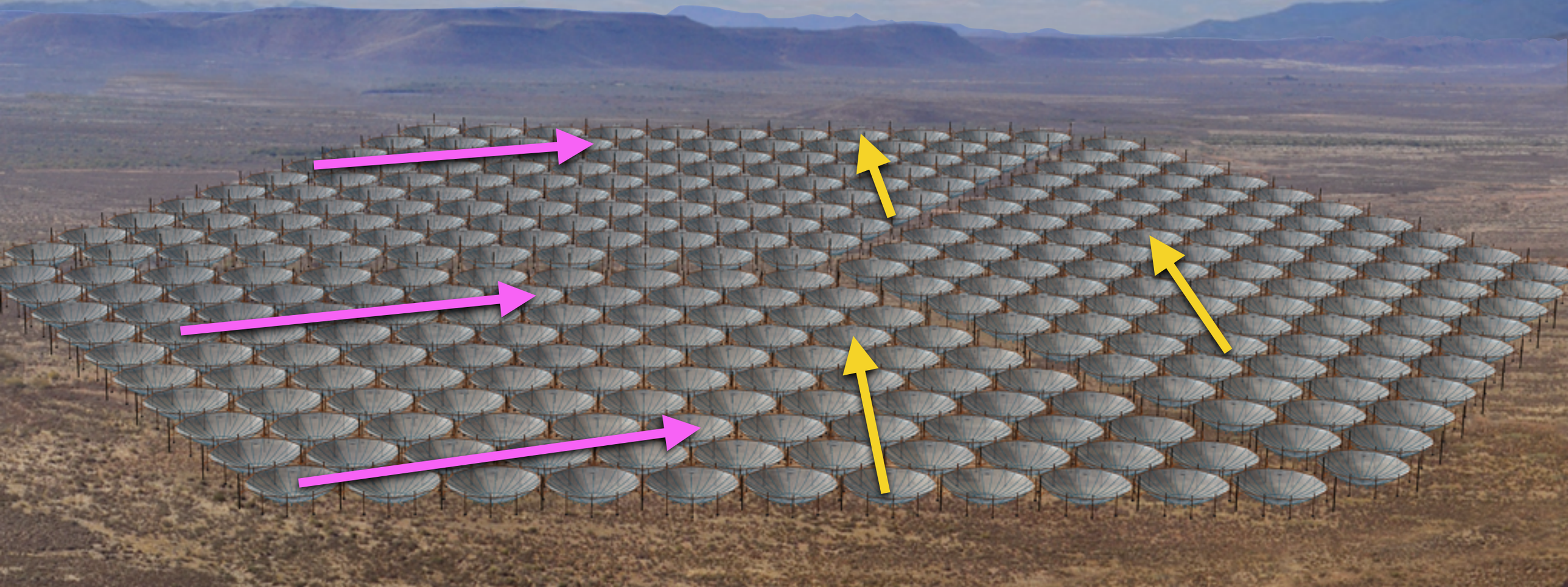
$$\sum m_\nu = 60 \pm 19\,\mathrm{meV} \longrightarrow \pm 12\,\mathrm{meV}$$

What drives the design of HERA? What are the similarities and differences when compared to a cosmology-centric 21cm instrument?

Why is HERA such a regular array?

A regular grid enables:

- Calibration via redundancy
- High sensitivity by repeated measurements of the same Fourier modes



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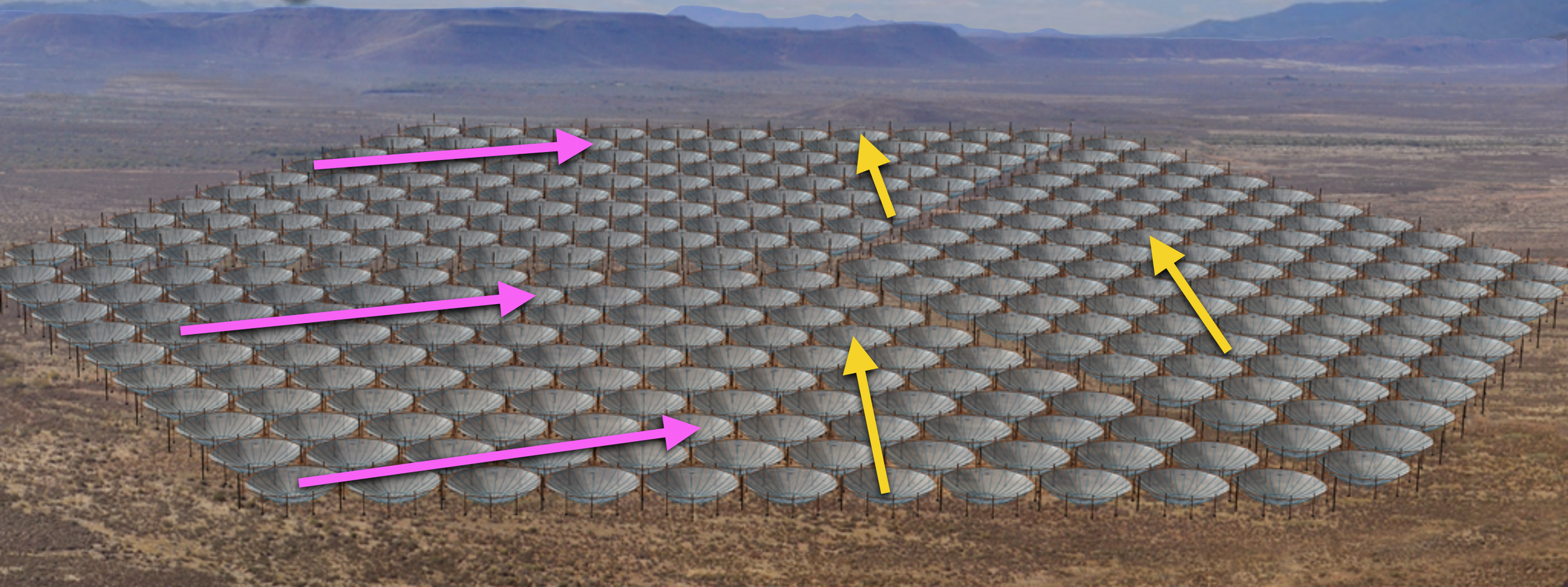
With the option of:

- Using FFT correlation



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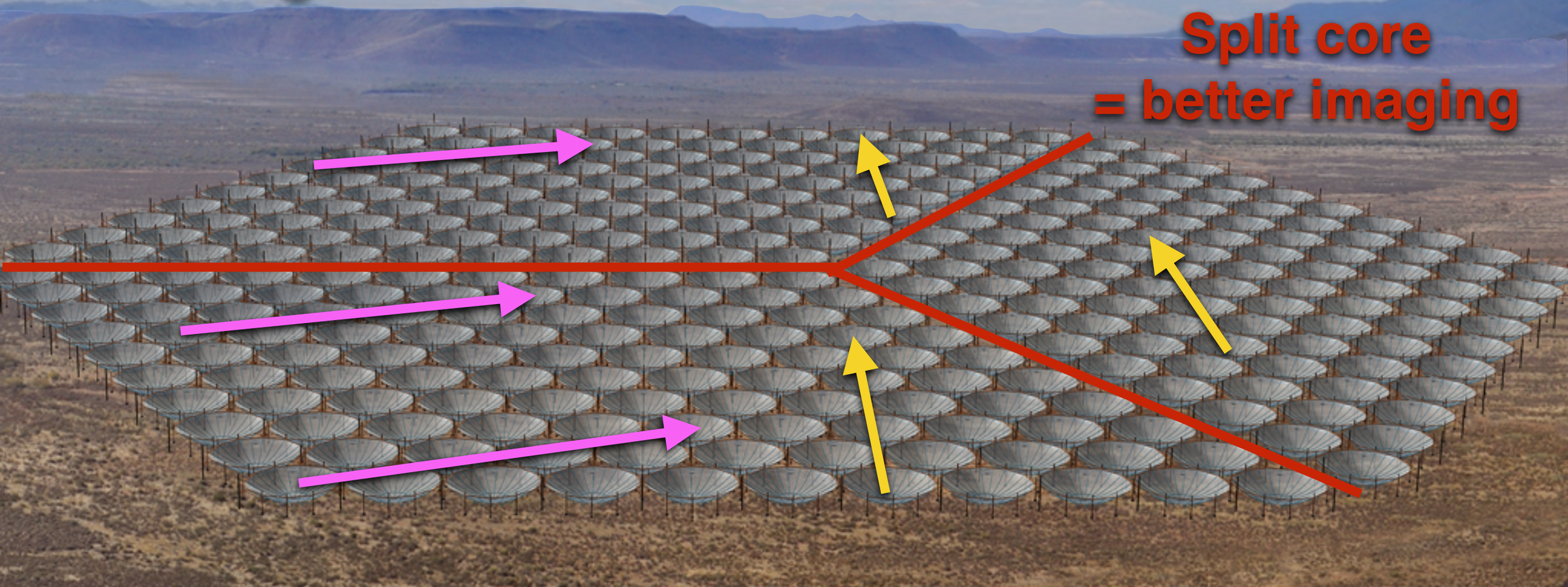


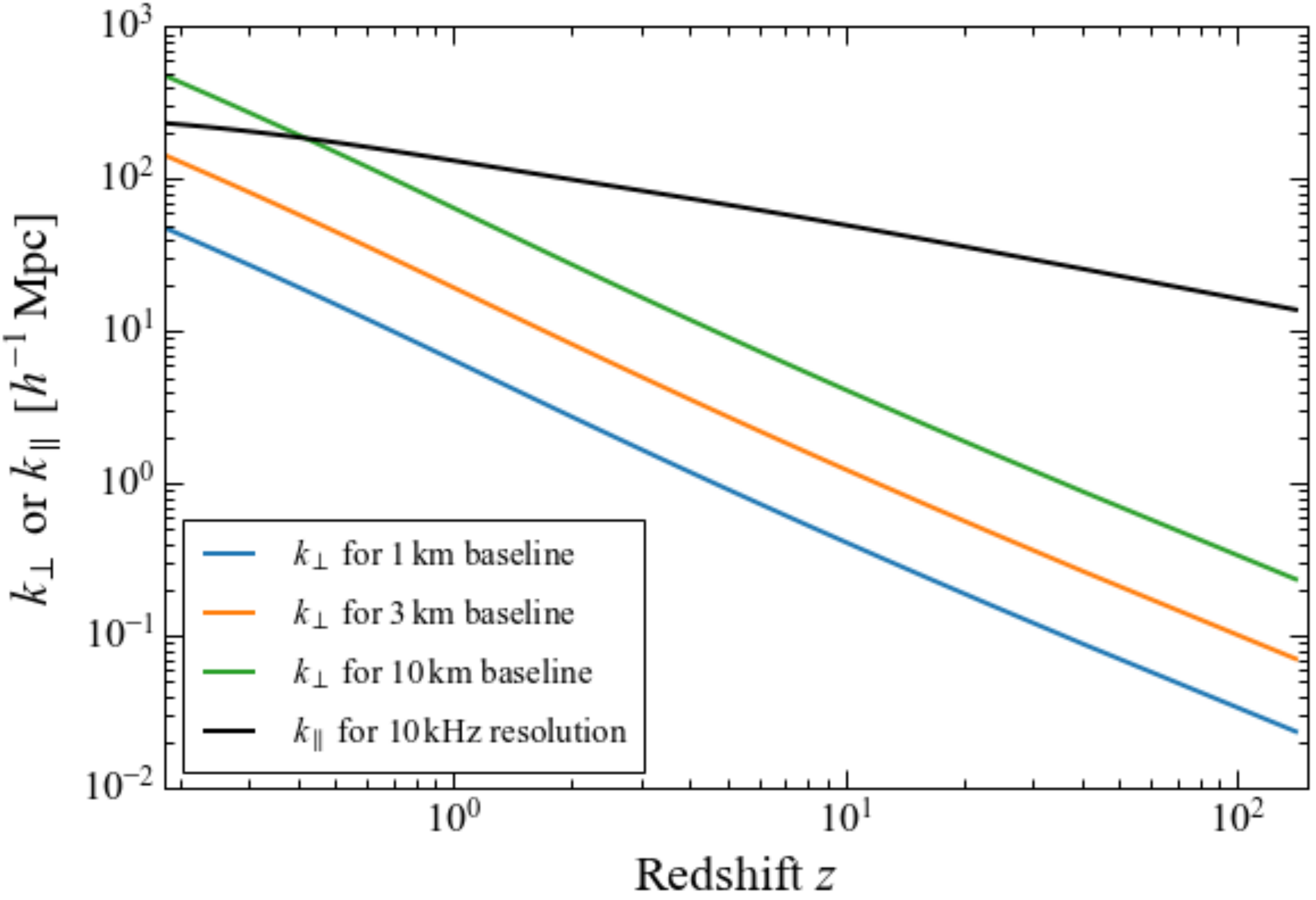
Why does HERA have such short baselines?

- Short baselines are less chromatic
- A compact array gives better thermal noise sensitivity
- High k modes are accessed along the line-of-sight anyway

21cm interferometers are not naturally C_ℓ instruments at high z

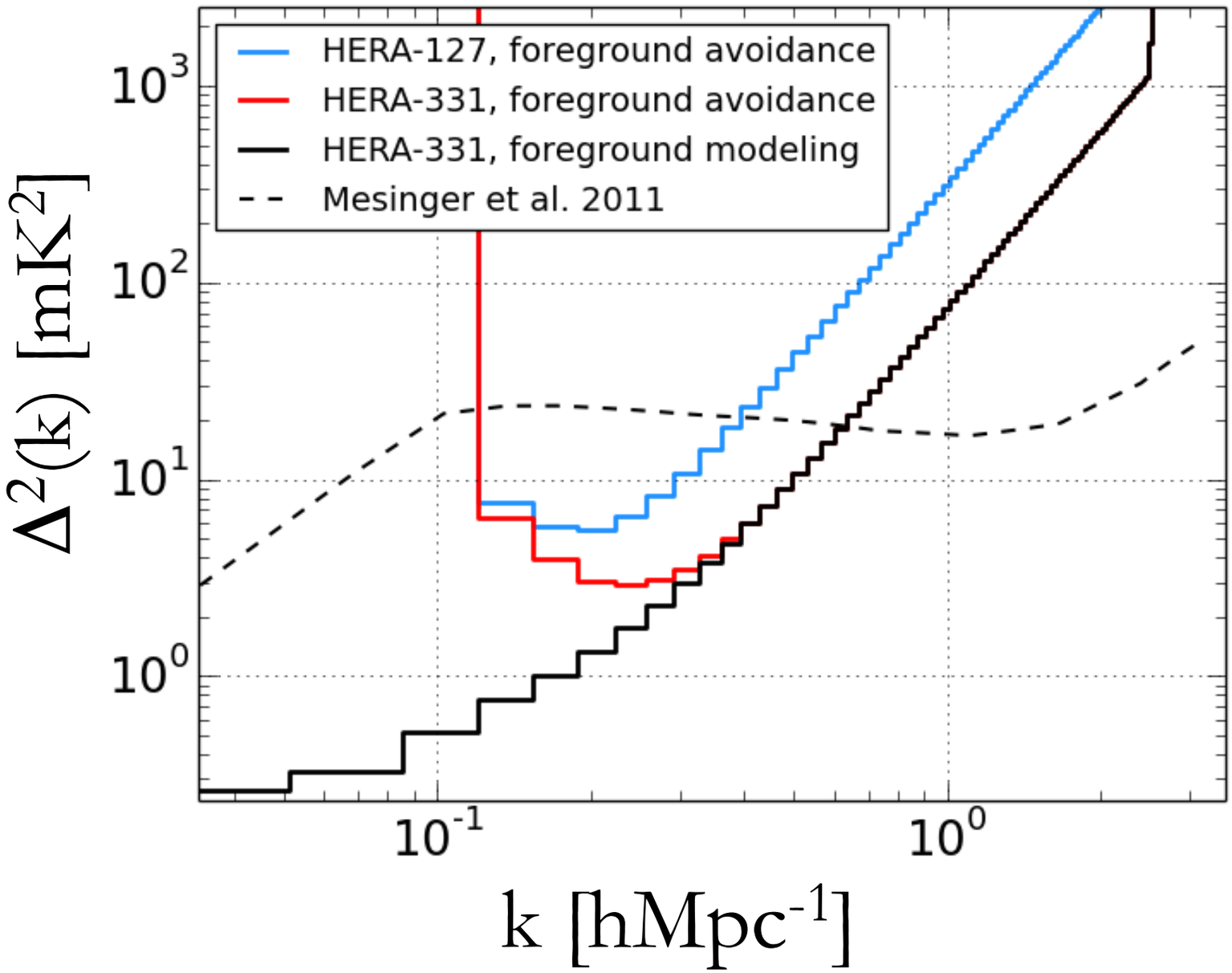
Max. baseline length

$$\ell \sim \frac{2\pi b}{\lambda} = \frac{2\pi b \nu_{21}}{c(1+z)}$$


10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
$k_\perp$ or $k_\parallel$ [h^{-1} Mpc]
$k_\perp$ for 1 km baseline
$k_\perp$ for 3 km baseline
$k_\perp$ for 10 km baseline
$k_\parallel$ for 10 kHz resolution
10^0
10^1
10^2
Redshift z

Why does HERA use such big dishes?

HERA's strategy is to work at high k to avoid foregrounds. Thermal noise is high there, so large collecting areas are necessary



Why not have smaller dishes, but have more of them?

- Having more dishes would require a much larger correlator to get to the same collecting area.

- Larger dishes have smaller fields of view, reducing the response to the horizon.

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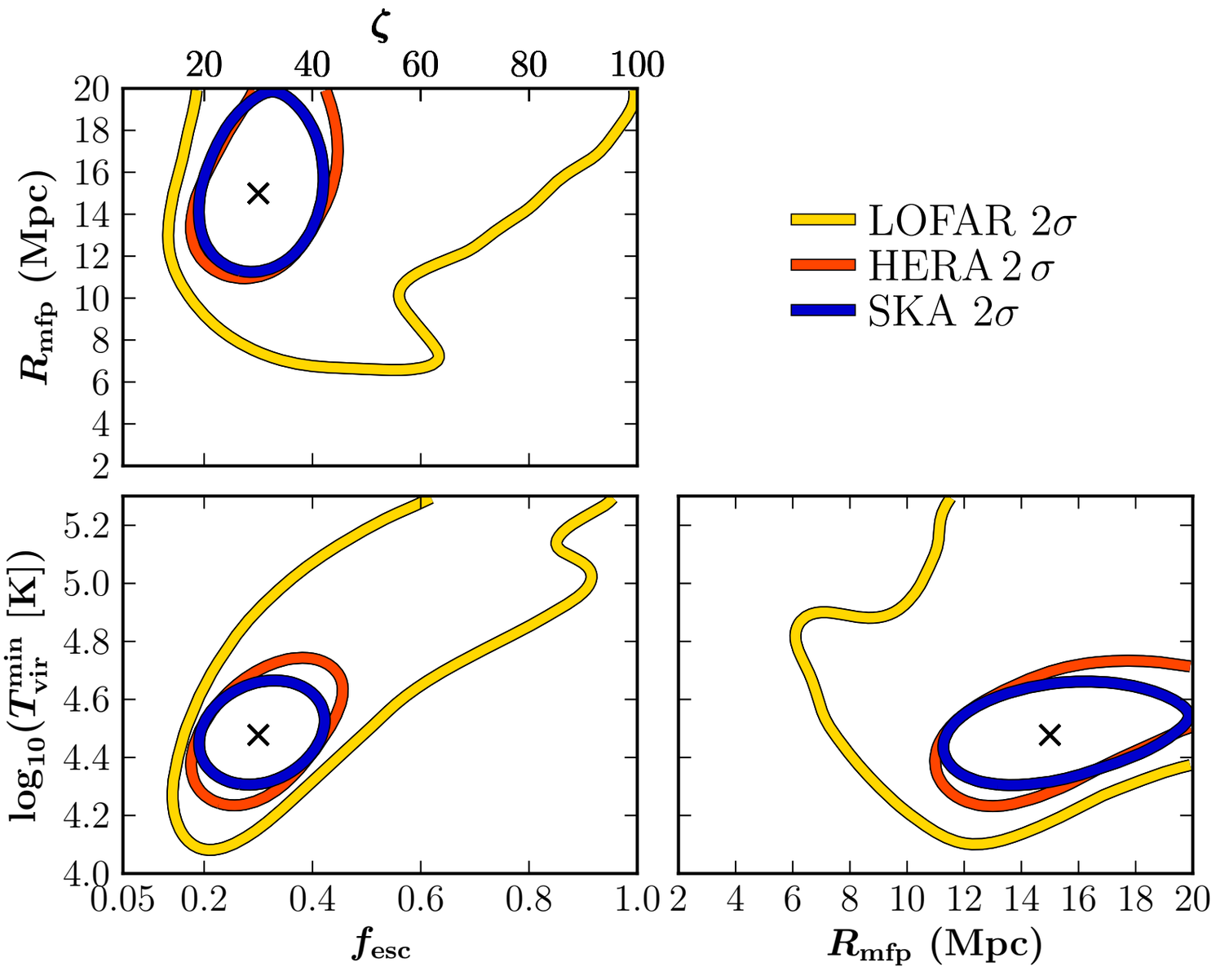
- This is not without downsides:

    - Cosmic variance? Likely not a problem.

    - Limited cross-correlation options with other surveys.

HERA is optimized for its science case, but various design parameters should be revisited for futuristic arrays



- Larger field-of view?
- Tracking?
- Faster (e.g. FFT) correlators?
- Will longer baselines/angular information become more necessary?